

SOFT MODELLING

OPEN SOURCE JAVA APPLICATION FOR FLEXIBLE STRUCTURAL SYSTEMS

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Contemporary advanced simulation software allow for a higher accuracy in the understanding of material behaviour. The increase in computational power is enabling designers to get much closer to real time physical simulations, which facilitates the inheritance of those tools in their design workflows. However, the use of those tools is normally limited to a series of specific steps within the entire workflow, rather than a feature integrated in the design process itself. Softmodelling is an open source Java application which aims to bridge this gap by seamlessly integrating physical simulations in every step of the design process, giving designers the ability to not only test structural behaviours of a given output, but also allow them to design while taking both structural stability and material behaviour into account at every stage. This paper will discuss the design and evolution of the software, as well as showcase physical prototypes which explore the possibilities of such design methods. These projects are fundamental in materialising the evolution of Softmodelling, towards becoming an application that does not only enable the design of flexible elements, but also facilitates their manufacturing and assembly into large scale structures.

Keywords: *Particle-spring systems, Dynamic relaxation, Physics Simulation, Flexible materials, Discrete Computation, Open source, Design Software*

INTRODUCTION

Simulation software for digital design

"Digital tools are a powerful ally of design by making, because digital simulations can make and break in no time more models than a physical craftsman could in a lifetime, thus making intuitive, heuristic form-finding by trial and error a viable design strategy. And when a model works, either a physical model or its digital equivalent, there may be no need to know or tell why." (Carpo 2012)

Contemporary advanced simulation software allow for a higher accuracy in the understanding of material behaviour. Software modules such as Maya dynamics, and Plugins for design software such as Kangaroo for Rhino/Grasshopper allow for innovative design methods, enabling users to understand material performance at different stages of the design process.

In addition, the increase in computational power is enabling designers to get much closer to real time

physical simulations, which facilitates the inheritance of those tools in their design workflows.

The increasing accessibility to those tools, as well as the proliferation of "easy to learn" simulation packages, has changed the nature of "flexible" structure design, establishing simulation-driven design as a new territory within CAD (Computer-aided design) software.

RESEARCH CONTEXT

From physical to digital form-finding

Since the introduction of simulation software in architectural design, they have been most commonly used as a digital form finding technique through dynamic relaxation (Day 1965).

Form-finding methods are those in which structures define their own shape under applied loads. The most commonly known examples deploying these methods in Architecture are:

- The hanging chain models used by Antonio Gaudi for Colonia Guell, wherein loads were distributed on the structure as weighted hanging chains. The pure tensile hanging geometry was then inverted, forming a compression structure optimized for that particular load case (Xie 2005).
- Frei Otto's experiments on tensile structures, which then materialised into large scale projects. The Munich Olympic Park for the 1972 Summer Olympics, or the Institute for Lightweight Structures, completed in 1967 at University of Stuttgart in Vaihingen are examples of these methods.

In these examples, membranes are solely working under tension, suspended from a multitude of vertical masts. Both given examples were developed in an analogue domain. Performing these experiments digitally allows for much faster and more accurate workflows, since "digital simulations can make and break in no time more models than a physical craftsman could in a lifetime" (Carpo 2012).

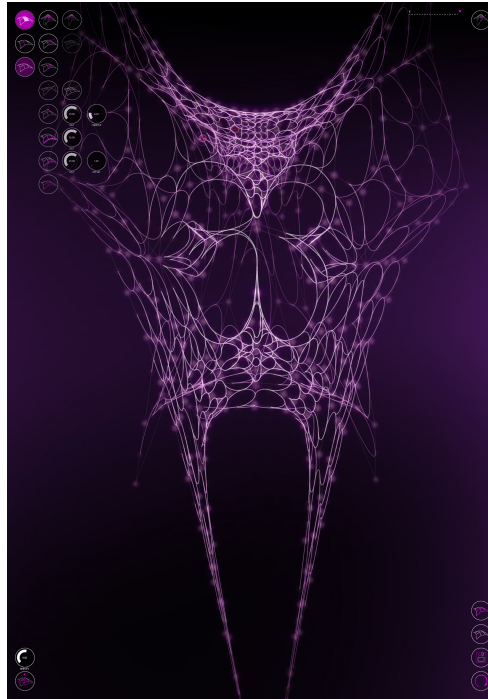


Figure 1
Softmodelling
interface developed
in Processing.
Render mode with
active conversion
from faces to linear
elements.

However, in architectural design, digital simulations often become a second step for previously completed schemes, where a modelled structure is transformed into a "physically active" object. The topology of that structure needs to be therefore fixed prior to its conversion into an active membrane. This takes digital form-finding slightly far from the playfulness of the design processes followed by Frei Otto or Antonio Gaudi, where local modifications to the structural setup can occur simultaneously to their physical performance. This results in singular processes compiled into a series of operations, rather than a feature integrated in the design process itself. The workflow progresses as follows: the designer models a structure, then applies physical forces, remodels it in case of any undesired results. After the physical simulation is completed, the user is unable to intervene in the resulting design, since any topological modifica-

tions to the object will need to be followed by a new physical simulation.

Limitations of physical simulation in computational design

Some software packages and simulation plugins allow for further interaction with the object after becoming "physically active", allowing the addition of new elements to the "physical scene".

This is the case for Autodesk Maya NCloth and Grasshopper Kangaroo. However, the dynamic transformation of the scene is limited to the level of the object as a whole rather than to its specific topology. Thus, users can't perform any modelling operations, such as extruding or subdividing faces. Addition and subtraction of new objects to the scene are the limited operations possible.

The closest solution available is the reduction of the user interaction to merely particles and springs, interpreting those as objects. This allows for the addition of new members to a structure, as well as their dynamic subtraction. The structure can therefore be actively modified, growing or shrinking locally, or even breaking previously created springs. However, this limits the manipulation of the element to its low level structure, configuring itself as a tedious (non-intuitive) process. In turn, making the creation of faces a difficult procedure, which is crucial for design processes involving solid objects.

Poly-modelling physics.

Softmodelling (e.g. figure 1) is an open source Java application which aims to bridge this gap between poly-modelling and simulation, by seamlessly integrating physical simulations in every step of the design process, giving designers the ability to not only test structural behaviours of a given output, but instead allow them to design while taking both structural stability and material behaviour into account at every stage; The software developed by Manuel Jimenez Garcia creates a continuous feedback between poly modelling and physical simulations, it incorporates most basic modelling features present in off-the-shell design packages, connecting them to

physical simulations at all stages. Its strength relies on the design and manipulation of tensile structures, giving the user the ability to modify the topology of the object, while actively responding to physical forces.

The software redefines the use of particle-spring systems, establishing them as a step-by step transformative process. As a result, this allows the local manipulation of physical elements, through the use of common modelling techniques. The software seamlessly transforms mesh vertices into particles, and edges into springs; bringing forward an output that is both physically and geometrically precise.

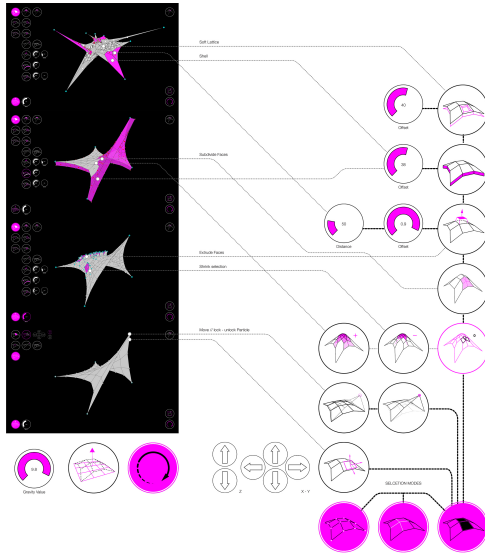
FLEXIBLE COMPUTATION

Design software for membrane structures

When working on specific structural types, the tendency is to use specialised software and plugins. In the case of membrane structures, software packages such as Membrane NDN, K-3 tent or Formfinder, are examples of such programs. However, those packages are closer to the development of a finished product, following an engineering approach, this makes them less practical for their use in early stages of the design process.

During those stages, modelling software, such as Autodesk Maya or 3DS Max, allow for more playful design methods, establishing themselves as the perfect tool to respond to the changing nature of a design in its conception stage.

Softmodelling situates itself as a design tool, in which playfulness and flexibility of poly modelling software packages are seamlessly integrated. It offers accuracy in structural form finding methods, offered by membrane engineering packages. This intends to offer a more extensive approach in regards to the manipulation of the structure. As a result, one is able to create different tensile morphologies beyond the commonly used Hyperbolic paraboloid, conic and barrel vault shapes. (e.g. figure 2)



Open source in design and simulation

"The freedom to study how the program works and change it so it does your computation as you wish [...] by doing this you can give the whole community a chance to benefit from your changes." (Stallman 2001)¹

Modelling software are commonly established as commercial packages, and therefore their source code is not accessible for users. Due to their commercial use, and the large number of users within design disciplines who depend on such software, the packages need guaranteed robustness in relation to their performance.

On the other hand, there are a vast variety of small applets and libraries which allow for concrete design operations. The open source character of those tools allow for the development of custom made applications, in which designers can focus on the integration of specific features, rather than having to develop a full package from scratch.

Softmodelling emerges from the integration of some of those libraries, into a software that intends

to bring a more complete modelling experience to those interested in the design of tensile structures. Its Open Source nature allows users to create their own version of the software, as well as contribute to its development, enabling the creation of more specific tools when required by the user's project.

The software is developed using Processing, developed by Casey Reas and Ben Fry, as a framework, and it makes use of a variety of open source libraries, such as Toxiclibs by Karsten Schmidt for physics simulations, HEMesh by Frederik Vanhoutte for half-edge meshes, Peasycam by Jonathan Feinberg for three dimensional navigation, and ControlP5 by Andreas Schlegel for the GUI integration.

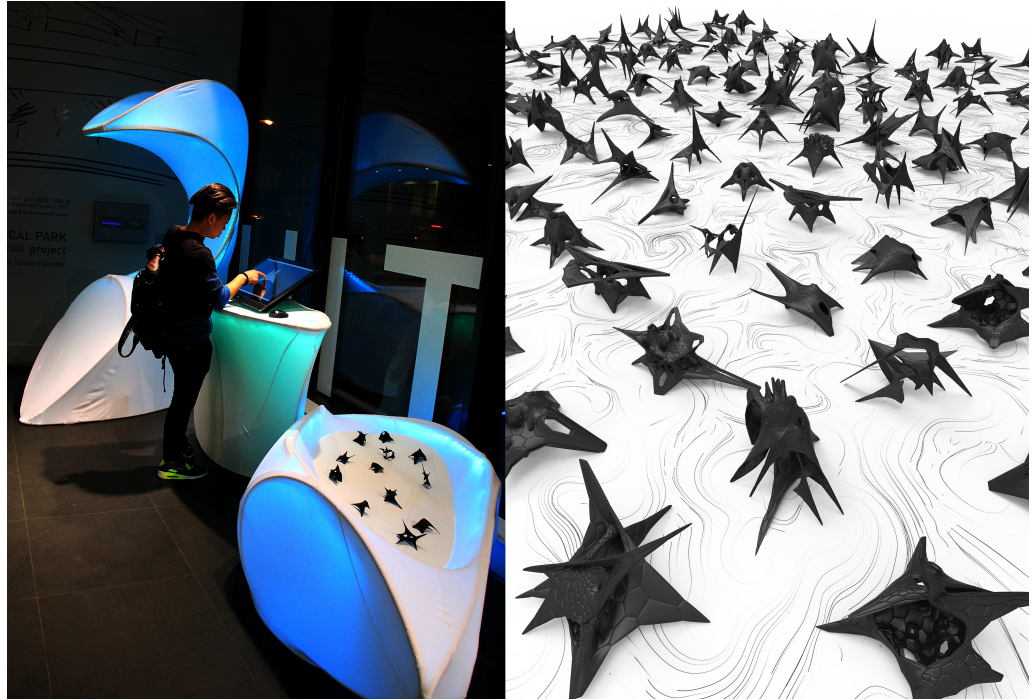
Responsive particle-spring systems

In commonly used 3d modelling packages, such as Autodesk Maya or 3Ds Max, physical simulations are considered to be post-design processes. This is a result of the recomputation of the mesh structure when any modelling operation is performed. Vertices and edges' indexes are recurrently recomposed. This constant transformation proposes a difficulty while matching the index of the particles to vertices and springs to edges. Therefore, the parity of both systems can't be guaranteed.

In order to avoid the constant negotiation between these two systems, most modelling software programs, with integrated simulation modules, fix all index numbers corresponding to the mesh components prior to the transformation of the object into a particle-spring system. Hence, any subsequent alteration in the meshes' topology is not taken into account in the physical simulation. When faces are extruded or subdivided, the new vertices do not become particles, and the new edges do not become springs. This produces a mismatch between the data structure of the mesh and its physical system, hence a deviation between the visual representation of the object and its performance in the simulation. Therefore, if any further adjustments should be performed to the morphology of the three dimensional mesh, the user is forced to return to a

Figure 2
Softmodelling -
Graphical map of
selection modes
and
mesh-manipulation
types.

Figure 3
Softmodelling 1.0
launch event - Left:
Installation for
London Clerkenwell
Design Week 2014
at the Actiu London
Showroom. Right:
Catalog of three
dimensional
models created
with the software.



previous stage and re-run the simulation after those adjustments are completed.

Softmodelling develops a strategy, to overcome the technical challenges regarding the most common poly-modelling operations. First, all index numbers of the particles and springs are relocated after any topological transformation is performed, this maintains the parity between the particle-spring system and their associated vertices and edges. Consecutively, a detailed analysis of the mesh identifies which elements have been affected by any topological transformation. The isolation of those areas allows for an increase in the system's efficiency, thus avoiding the use of computationally expensive processes in any other area of the object. Once the local data matching process is completed, particles and springs get reconnected to the new as-

sociated vertices and edges. This enables the object's physical properties to be updated with a new topological structure.

TOWARDS A DESIGN AND FABRICATION WORKFLOW

Data to matter and matter to data.

Softmodelling was first tested during Resonate 2014 in Belgrade, and was officially launched during London Clerkenwell Design Week (May 2014) at the Actiu London Showroom, where the software included its first multi-tactile interface. This allowed participants to create their own structures. The exhibition also included a series of 3D printed models designed by MadMDesign, which aimed to test the efficiency of the software as a design tool. The models



Figure 4
Trans-
Computational
Pavilion 1.0. -
Textile prototype
created during the
AA Visiting School
Madrid 2014.
Exhibited during
the X Week of
Architecture in
Madrid at COAM.
Design team:
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Guijarro, Juan
Rodriguez Martín,
Jose Luis E. Penelas,
and AAVSMadrid
2014 students.

were a response to the challenge set by Actiu London Showroom to create 24 different objects in only eight hours (e.g. figure 3). The feedback collected during the event was fundamental for the progression towards the next stages of the software.

Since then, Softmodelling has been tested in several workshops and installations, aiming to resolve medium scale structures through the use of flexible materials. Alongside this process, the contribution of workshop participants has resulted in the creation of a variety of pavilions and installations, aiming to measure both material behaviour and the efficiency of the software as a design/fabrication tool.

The material experiments and physical studies that took place during these several events became extremely instrumental to the development of the software. This paper will focus on two installations, which correspond to the two stages of the software's development: membrane structures manipulation,

and flexible tubular elements which perform in a structural symbiosis with the membrane itself.

HYBRID FLEXIBLE STRUCTURES:

Softmodelling 1.0

The prototypes developed during the first stage, make use of the force density methods (Schek 1974) integrated in the software to create inhabitable structures. These structures, are driven by basic principles of rapid reoccupation systems, which offer a variety of flexible spaces. The prototypes were conceived from the idea of utilising low cost materials with a high degree of flexibility. Interweaving these flexible elements together, in order to create localised stiffness in areas of the structure with higher stress levels, results in increasing the overall stability of the structure.

A series of pavilions are developed as an output of Softmodelling, through an assemblage of two

Figure 5
Installation for
London Clerkenwell
Design Week 2015
at the Actiu London
Showroom. Flexible
structures - Design
team: Manuel
Jimenez Garcia,
Roberto Garcia,
Miguel A. Jimenez,
Ignacio Viguera.



types of flexible materials: PVC pipes and stretchable textiles. While the PVC pipes bundle into structural objects, the textile pieces get stitched together to generate continuous surfaces. Thus the multiple membranes generate compression forces to encourage the PVC pipes to stay connected, while the linear structure simultaneously pushes the membranes to maintain their state of tension. This results in structural balance producing stiffness within the architectural element.

Computational membranes

Prior to the official launch of the software, a primitive version of Softmodelling was used for the design of the first large scale pavilion in this research, executed during the AA Visiting School Madrid 2013 (e.g. figure 4). Due to the technical limitations of the application in its early stages, the construction was created as a result of an intuitive process, rather than as a product of digital fabrication workflows. Regardless of the lack of continuity between the digital model and the physical prototype, this testing pro-

cess allowed for the first establishment of structural elements. This, as a result materialised a link between material density, connectivity and stretching.

Later prototypes created with this system include the second iteration of the AA Visiting School Pavilion, in 2014 (e.g. figure 5), as well as the installation for London Clerkenwell Design Week 2015 (e.g. figure 6-7). Both projects offered a smoother workflow between the software and the fabrication method. However, the fact that the software only offered surface manipulation and dismissed the integration of the frame, became an apparent limitation. This created a clear necessity for SoftModelling to incorporate a new feature which would allow for the creation of linear structures that work in conjunction with the general topology.



Although this feature is not yet fully completed, SoftModelling 2.0 does offer a conversion from faces to linear elements. This aims to create new workflows in which designers can not only control a tensile structure with external anchor points and frames, but also create the frame itself. This is based on a combination of multiple bended linear elements which connect to create a structure in perfect equilibrium.

The modularisation of the linear elements; which bend differently to be assembled into larger objects, brings a higher degree of control to the structure. The fixed lengths of the pieces not only simplifies their computation, but also the manufacturing process, which as a result allows for the use of simpler digital fabrication methods.

DISCRETE BENDING : *Softmodelling v2.0*

"Digital materials consist of a finite set of parts that have discrete connections and occupy discrete space." (Ward 2010)

As previously mentioned, the second stage of the software development focuses on the flexible linear elements rather than on the membrane itself. The aim is to generate a series of discrete flexible pieces that maintain the membrane in a state of tension. However, in order to conserve the intuitive nature of Softmodelling as a design tool, the distribution of those pieces must be linked to the topology of the mesh. The most recent version of the software offers a conversion from faces to linear elements. This aims to create new workflows in which designers can not only control a tensile structure with external anchor points and frames, but also create the frame itself (e.g. figure 8).

This feature was tested in several installations where the bendability and connectivity of flexible elements were further explored. The projects corresponding to this second stage of research, aim to isolate the structural integrity to discrete flexible elements. Therefore, the integrity of the structure is more dependent on the contribution of these aforementioned elements rather than the on the membrane itself.

Discrete computation for flexible linear elements

The installation at Dezact, entitled Offshore Bezier (e.g. figure 9), is the largest prototype exploring this combinatorial arrangement of linear elements. One of its primary aims is it to explore the material behaviour of linear elements in a large scale. In this occasion, a vernacular material was explored and vastly available in the area: bamboo. Even though bamboo, in terms of material performance is stiffer than the PVC pipes used in previous installations, the geometrical logic for their arrangement remains the same. Despite early attempts at digitally manufacturing the nodes between the elements to achieve higher control over the structure in relation to its digital replica, the use of SoftModelling was limited to an approximation of the structural arrangement rather than as a fabrication tool. The software however, proved that this arrangement can be linked to stress anal-

Figure 6
Trans-
Computational
Pavilion 2.0. -
Flexible structure
based on linear PVC
elements.
Photography taken
prior to the
addition of the
textile membrane.

Figure 7
Trans-
Computational
Pavilion 2.0. -
Completed flexible
prototype, created
during the AA
Visiting School
Madrid 2015.
Exhibited during
the XI Week of
Architecture in
Madrid at Roca
Madrid Gallery.
Design team:
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Garcia, Antonio
Guijarro, Maria
Olmos, Miguel A.
Jimenez, Ignacio
Viguera, Jorge
Cerdá, Marina
Rodriguez, Vicente
Soler, Silvia Rivera,
Maria Olmeda, Jose
Real, Jose Luis E.
Penelas, and
AAVSMadrid 2015
students.

ysis and therefore the distribution and connectivity of discrete linear elements can be controlled in real-time during the modelling stage.

CONCLUSION

The aforementioned projects not only configure a showcase of the possibilities of such design methods, but also contribute to generating data which informs the development of the software. The evolution of the software towards digitally controlling the assemblage of flexible elements, facilitates the ability to achieve higher degrees of complexity in the generated structures.

This configures a new territory in the domain of flexible structure design. Maintaining the high level of control of such structures through simple modelling operations, configures a unique feature of Soft-modelling. However, controlling both membrane and frame while maintaining the playful character of

the software, becomes a challenge yet to be resolved.

The next stages of the research and development of SoftModelling will tackle the refinement of the linear elements in the digital realm, introducing physical testing for their bending moments and their structural performance. This will be achieved through redefining the relationship between the linear elements and the faces of the object. By establishing these elements as separate entities independent of each other, the digital model will resemble a closer configuration to the reality of the built structures, while maintaining the intuitive nature of Soft-modeling as a design tool.

Furthermore, the development of a robust fabrication module becomes essential for the construction of future large scale prototypes. The module should enable the smooth translation of digital data from Softmodelling into robotic instructions. This should not only enable the fabrication of discrete el-



Figure 9
OffShore Bezier. -
Installation
produced during
Dezact 2015 (Extra
Fabrica) at Shin
Chien University,
Taipei. Hanging
structure
configured as an
assemblage of
bamboo
pipes. (Photography
by Dezact). Design
team: Manuel
Jimenez Garcia,
Christina Dahdaleh,
and Dezact 2015
students.

ements, but also simplify the assembly process. The installation for Dezact Taipei 2016, will mark the first attempt at testing this process. Tool paths for two Universal Robots (UR) working collaboratively are being developed. While these two robotic arms perform bending operations on the linear elements, a third UR, equipped with a custom-made heating end-effector, moves along the previously bended element to keep its shape after completion of the process.

These steps attempt to fill the gaps in the design to fabrication workflow, intending to offer a continuous experience from the conception stages of flexible structures to their materialisation. This will be a fundamental milestone in the development of Soft-modeling. The Dezact project is to be completed in August 2016.

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